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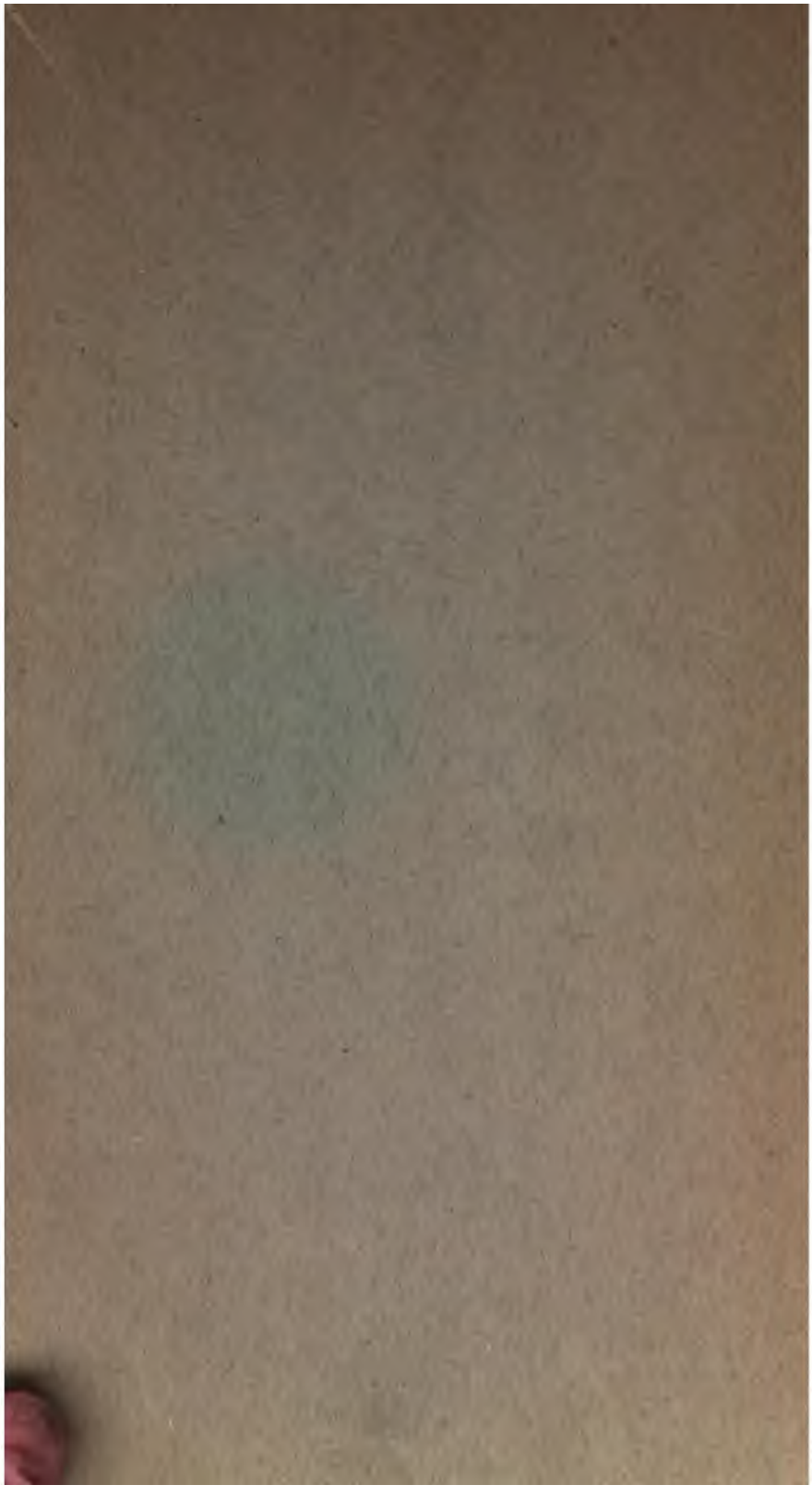

AMERICAN SOCIETY OF CIVIL ENGINEERS.

# MEMOIR

OF THE CONSTRUCTION OF A

# MASONRY DAM FOR A STORAGE RESERVOIR.

BY

J. JAMES R. CROES, C. E.

THE PAPER FOR WHICH THE NORMAN MEDAL WAS AWARDED, NOVEMBER 4TH, 1874.

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# THE NORMAN MEDAL FOR 1874.

At the Annual Meeting of the American Society of Civil Engineers held at the rooms of the Society, No. 63 William street, New York city, on November 4th, 1874, the President, for the Board of Censors to award the Norman Medal, presented the following report :

"The undersigned, a Board of Censors to select from the papers submitted in competition for the Norman Medal, such one as in their judgment best meets the views of the founder and the true interests of the Society, beg leave to report that the 'Memoir of the Construction of a Masonry Dam,' a paper submitted without other mark of identification, is entitled to the Norman Medal for 1874."

JULIUS W. ADAMS,
*President American Society of Civil Engineers.*

JOHN G. BARNARD,
*Colonel of Eng'rs, B'vt. Major General, U. S. A.*

F. A. P. BARNARD,
*President Columbia College.*

# CODE OF RULES

FOR THE

# AWARD OF THE NORMAN MEDAL.

I. Competition for the Norman Medal of the American Society of Civil Engineers shall be restricted to members of the Society.

II. There shall be one gold medal, and only one, struck for each and every fiscal year of the Society, and awarded as hereinafter provided. The dies therefor shall be with the superintendent of the United States mint at Philadelphia, in trust exclusively for the aforesaid purpose. Such medal shall be of a cost equal to the annual interest received upon $1,000 of the consolidated stock of the city of New York, certificate No. 179, of additional new Croton Aqueduct stock of the city of New York, authorized by an act of the Legislature of the State of New York, Chap. 230, passed April 15th, 1870, dated November 17th, 1873; now held in trust by the Treasurer of this Society, and so held solely for this purpose; and shall be executed upon his order.

III. The President of the Society, the President of Columbia College, and the Engineer Officer of the United States Army commanding in that capacity in New York city and vicinity, shall be, ex-officio, a Board of Censors, whose duty it shall be to examine all papers entitled to competition under these rules, and award the Norman Medal as a prize of merit, as hereinafter provided.

IV. No papers shall be entitled to competition except such as are of practical engineering interest; it being the expressed intention of the donor to exclude from competition all papers of a purely speculative or theoretical character.

V. Each paper submitted for competition shall be headed with the title, but shall not exhibit the author's name on any part of the manuscript; it shall be accompanied with a sealed envelope, superscribed with the title, and enclosing both the title and the name of the author. The whole to be enclosed in an envelope addressed to "The President of the American Society of Civil Engineers," and conspicuously endorsed "For Norman Medal, year.....;" and presented at least two months prior to the Annual Meeting; and no paper otherwise presented, or in possession of the Society, shall be admitted to competition, nor except for the fiscal year in which it shall have been presented.

VI. All papers presented in accordance with the foregoing rule shall first be submitted by the President to the Board of Censors; and after their examination, and at the Annual Meeting, the President shall present the successful essay, together with the sealed envelope containing the author's name, accompanied with the certificate of the Board of Censors, to the Society—when the envelope shall be opened, the author's name announced and the award declared. Such award shall be entered on the Minutes and published in the proceedings of the Annual Meeting. If for any reason, in any year, there shall be no award of this medal, then the amount of the interest of the fund for that year shall be expended by the Board of Direction in the purchase of books; said books to be offered as a premium for the second best competing paper for the medal of the succeeding year.

VII. The Treasurer of the Society shall cause the medal to be prepared and delivered to, or deposited to the order of the successful competitor, within two months after the Annual Meeting at which the same shall have been awarded.

VIII. The Board of Censors may make such regulations, consistent with this Code, as they may deem proper, and shall have power to fill vacancies in said Board.

At the regular meeting of the American Society of Civil Engineers, held on the 3d day of February, 1875, the President, Mr. Julius W. Adams, addressed the Society as follows :

" Mr. George H. Norman, a member of this Society, with a liberality which, I take this occasion to say, will ever entitle him to the warmest gratitude, not only of the Society who are directly benefited by his munificence, but of the public at large, who, not less than ourselves, are interested in all that relates to the substantial improvement of our profession, has invested and made over to the Society a fund, in safe securities, the income from which is to be appropriated yearly to the preparation of a medal in gold, as a premium for the best essay, memoir or paper offered in competition, on some branch of practical engineering.

" The dies have been prepared, the medal struck, and you have before you the first premium which the American Society of Civil Engineers has been enabled to offer to its members as an earnest of its intentions and aims, outlined in the first article of our constitution, as ' the professional improvement of its members and the advancement of engineering in its several branches.'

" In our infancy, and, we may truthfully add, in our poverty, we could offer but little save our individual exertions to the furtherance of this end. Silver and gold we had none, and with the exception of the *hope* to lay the foundation of a library, the means through which we proposed to bring about great results were perhaps somewhat disproportioned to the end in view, but it was all we could promise at that day with any hope of redemption. Thanks to a Past President of the Society, we may say that we have the nucleus, if not the foundation, of a library ; and now, through the munificence of one of our members, we have the institution of the Norman Medal.

" The Board of Censors for the award of this medal, having, with perfect unanimity, chosen a paper as fulfilling the intention of the founder of the premium, it becomes my official duty, as your presiding officer, to declare the award of the medal, for the year 1874, to Mr. J. J. R. Croes, of New York, for his Memoir of the Construction of a Masonry Dam."

Then, addressing the recipient of the medal, the President continued :

" In presenting this, the first Norman Medal, allow me to congratulate you, Mr. Croes, on the preparation of a paper, the value of which is not to be measured by the limited extent of the competition in which it bore off the prize, nor by the unusual character of the structure itself, which constituted the theme of your memoir ; neither by its magnitude,

nor the important functions it is destined to perform in the future of this great city ; nor by reason of the fitness of the design of the work to meet the end in view ; but for the clear, concise and able treatment you have exhibited of that portion of the duty of a constructing engineer which, constituting his personal experience merely, is either thought of too little value for preservation in a useful shape, or if preserved, is locked up in an undigested form in his private note-book, and is thus of no value to his professional brethren. These are, on the contrary, when well put together, the most valuable contributions which the engineer can present to his younger brethren. The value of analytic investigation embracing the higher calculus should not be overlooked ; but the engineer will remember that it is at best but a means to an end, and that the end sought shall be attained, the *facts* are of the first consequence, or, as Professor Huxley has very forcibly put it, 'Mathematics may be compared to a mill of very exquisite workmanship, which grinds you stuff of any degree of fineness, but nevertheless, what you get out depends upon what you put in ; and as the grandest mill in the world will not extract wheat flour from peas cods, so pages of formulæ will not get a definite result out of loose data.' "

Mr. Croes replied in these words :

" I receive this medal at your hands, Mr. President, with feelings of gratification which I will not attempt to conceal. I will not say I thank you and your colleagues of the Board of Censors, for *thanks* imply a personal favor conferred, and the conditions and mode of award of the Norman Medal preclude the entrance of personal considerations into the matter. I may, however, and do, thank you for the kind terms in which you have expressed your approval of the scope and mode of treatment adopted in the paper which has been so fortunate as to receive the first of what we hope will be a long succession of annual rewards, each of which will be a token to the recipient that his labors have not been altogether in vain—a token to the members generally that careful observation of facts and principles will not be overlooked—a token to those outside of the profession that the American Society of not merely hydraulic, not merely mechanical, not merely railroad or topographical or bridge engineers, but of that which includes all these—of civil engineers—is in earnest in its endeavors to elicit from each of its members that which will benefit them all, and by benefiting them be of advantage to their clients, and these include all men whose condition can be bettered by public improvements."

DAM AND RESERVOIR 1874. LOOKING NORTH.

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# AMERICAN SOCIETY OF CIVIL ENGINEERS.

## MEMOIR OF THE CONSTRUCTION OF A MASONRY DAM.

A Paper by J. JAMES R. CROES, C. E., Member of the Society.

FOR WHICH THE NORMAN MEDAL WAS AWARDED

NOVEMBER 4TH, 1874.*

PRELIMINARY.—§ 1. The dam described in the following paper was constructed on a branch of the Croton river, in Putnam county in the State of New York, by the Croton Aqueduct Board, the department of the government of New York city which was charged with the construction and maintenance of works for the supply of water to the city.

§ 2. The object of the dam was the creation of a reservoir for storing water to supply the deficiency in the daily yield of the stream which existed during the summer months of dry years, the minimum flow being not more than four million cubic feet per day, while the consumption had reached double that amount, and was rapidly increasing.

§ 3. The necessity for artificial storage reservoirs had long been foreseen by Mr. Alfred W. Craven, the chief engineer and a member of the Croton Aqueduct Board since its organization in 1849, and in 1857–58 he had caused a topographical survey of the water-shed of the Croton river to be made, with a view to determine available sites for such reservoirs. The survey showed that fourteen such sites existed; but not until April, 1865, was the requisite authority procured from the Legislature to construct a storage reservoir.

* The Board of Censors in awarding the prize of the Norman Medal of 1874, to this paper on "The Construction of a Masonry Dam," wish it to be understood, that such decision must not be considered as the expression of an opinion on their part, as to the correctness of the views entertained by the author, but that the paper, in the treatment of the subject, serves as a model in their judgment for the class of papers, the production of which, it was the intention of the founder of the premium to encourage.

J. W. ADAMS, Pres. American Society of Civil Engineers,
F. A. P. BARNARD, President Columbia College,
J. G. BARNARD, Colonel of Engrs., Brt. Major-Genl. U. S. A.,
} Board of Censors.

November 4th, 1874.

§ 4. Nearly a year was consumed in careful examination and comparison of sites, and on March 17th, 1866, it was determined to build a reservoir at Boyd's Corners on the west branch of the Croton, 23 miles by the course of the stream from the Croton Dam, where the aqueduct begins which conveys water to the city.

§ 5. The reservoir as constructed here, has a water surface of 279 acres, a maximum depth at the dam of 57 feet, a mean depth of 30 feet, and a capacity of 364,000,000 cubic feet.

§ 6. At the site selected for the dam, the hills enclosing the valley approach each other, leaving at the level of the stream a space of only 200 feet in width, and at 70 feet above the stream, 700 feet. The centre line of the dam is at right angles to the axis of the valley at this point, and bears nearly north-east and south-west.

§ 7. The north-easterly hill-side was covered with large slabs of a very compact and fine and even-grained gneiss, piled one upon another, varying in thickness from 6 to 60 inches. The rift of the stone was at right angles to the bed on which it lay; the slabs were at an angle of 10°, and the general slope of the hill was 16½°. The ledge underlying the slabs was of much the same character, but not quite so fine grained. The general surface was smooth, and sloping at the inclination of the hill. Occasional seams were found to run in nearly horizontally, from 5 to 20 feet, then apparently terminating abruptly. The surface slabs made excellent stone for cutting where they were of sufficient thickness to give the requisite beds. It was found impracticable to quarry out of the ledge, good stone for cutting.

§ 8. At an elevation of 15 feet above the stream, the rock was overlaid with about 10 feet of drift, or compact gravelly earth, containing about ten per cent. of its bulk of large boulders. The flat ground through which the stream flowed was swampy on the surface, underlaid by some blue clay, beneath which was a mass of loose boulders and cobble stone, which was succeeded by coarse gravel and sand which extended to the rock, and through which a considerable amount of water percolated.

§ 9. The south-west hill, rising at an angle of 22°, was composed of compact gravel and boulders, overlying a very fine grained unstratified hard blue rock. The surface of this rock was smooth, but its profile irregular and in benches. It lay at a depth of from 5 to 15 feet below the surface of the ground. In the centre of the valley the two classes of rock seemed fused together, no marked seam separating them. The rock here was 18 feet below the stream level.

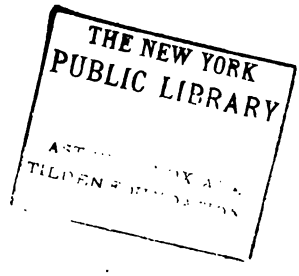
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Fig. 1.

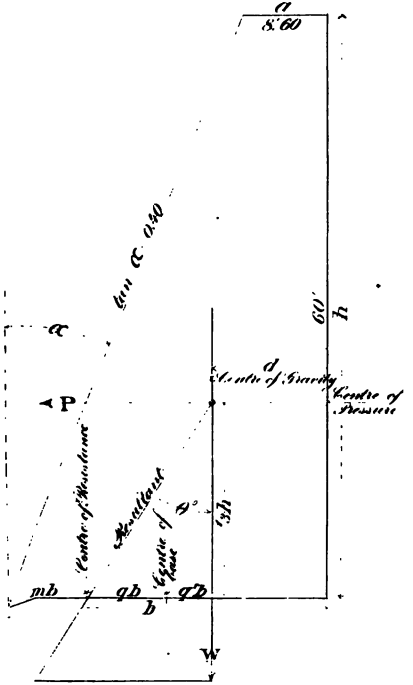



Fig. 3. S. 88.

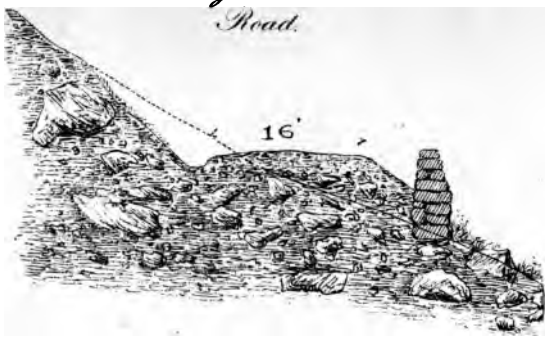



Fig. 4. S. 84.

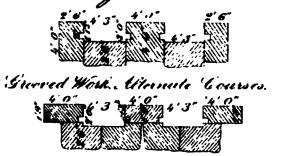
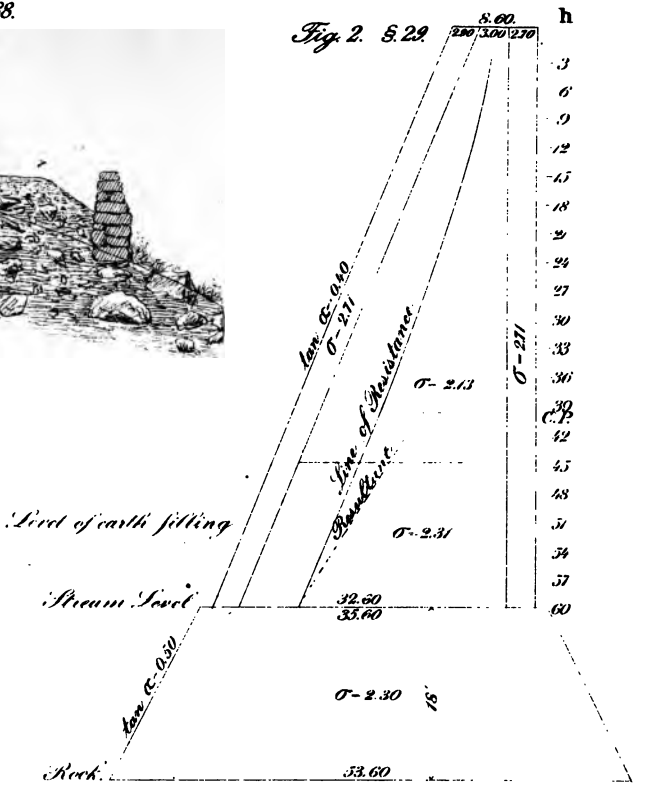



Fig. 2. S. 29.

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§ 10. No dam at this place could be made safe or water-tight, without removing all the natural material and founding the structure on the rock. All the earth within a mile of the dam site contained so large a proportion of boulders and coarse gravel as to render it unfit for water-tight embankment, except at enormous expense for separating and screening out the stone. An earthen embankment would have demanded for safety, a tunnel through the rock of the hill-sides for the discharge-pipe at the stream level, and a rock cut of some 15,000 cubic yards in the hill-side at flow line, for waste water.

§ 11. The stream was liable to sudden and severe freshets which could not be prevented from overflowing the dam during construction. Such a freshet would necessarily destroy a partially completed earth embankment.

§ 12. An abundant quantity of stone of excellent quality lay on the hill-sides within a short distance of the dam site.

§ 13. These considerations led to the decision that the dam should be of masonry. Below the level of the stream, the foundation is composed of concrete in which are imbedded large unwrought stones. Above the stream level, the concrete hearting is faced on both sides with coursed stone with cut beds and joints; for 15 feet above the stream, large unwrought stones are imbedded in the concrete; and above that elevation, the hearting is entirely composed of concrete of small stones.

Form and Stability.—§ 14. The form of a trapezoid with a vertical face opposed to the water, was adopted, as affording the requisite stability with the least amount of material and least difficulties of construction. The form and dimensions of the wall are shown in Fig. 1. The notation used is as follows:

$h$ = height of wall, or distance from top to any bed joint.

$a$ = top width of wall.

$\alpha$ = angle of inclination of face of wall, to the vertical.

$b$ = width of wall at any bed joint at the distance $h$ below the top = $a + h.\ tan.\ \alpha$.

$d$ = horizontal distance of the centre of gravity of the section of the wall, from the vertical face. For a homogeneous wall of this form, $d = \frac{1}{3}\left(a + \frac{b^2}{a + b}\right)$.

$P$ = pressure of water on the vertical face = $\frac{h^2}{2}$ when the weight of a cubic foot of water is taken at unity.

$\sigma$ = specific gravity of the material of the wall.

$W$ = weight of wall = $\frac{\sigma\, h}{2}(a + b)$.

$\Theta$ = angle of inclination to the vertical of the resultant of pressures, $\therefore$ *tan.* $\Theta = \frac{P}{W}$.

$m$ = ratio which the distance from the exterior edge of the bed joint to the point where the resultant of pressures intersects that joint, has to the whole width of the joint or $b$; $\therefore m = 1 - \frac{d + \frac{1}{3} h.\ tan.\ \Theta}{b}$. To insure there being no tension on any part of the bed joint, $m$ must not be less than 0.333.* In practice, English engineers are said to adopt as a safe value $m \geq 0.125$, while the French engineers adopt the limit $m \geq 0.2$. In the calculations for this dam, the limit is taken $m \geq 0.25$.

$n$ = ratio which the deviation of the centre of pressure at a bed joint, from the perpendicular let fall from the centre of gravity, bears to the whole base. This ratio is the same as $(q + q^1)$ used by Rankine. From the figure $n = \frac{h}{3\,b}$ *tan.* $\Theta$.

$\varphi$ = angle at which one stone will slide upon another.

§ 15. In all the calculations for the wall, it is assumed that the water will stand at the level of the top of the wall, although the flow line of the reservoir is 3 feet lower. This assumption simplifies the calculations, and provides against any contingencies which might arise in freshets. It is also assumed that the bed joints are horizontal. The batter of the face wall, and the fact that the joints of the courses there are normal to the face, make the bed joints practically inclined to the horizon, and therefore presenting greater resistance to sliding and overturning, than is assumed in the calculations.

§ 16. For purposes of calculation these values are assumed—specific gravity of the masonry, $\sigma = 2.33$; the limiting angle of sliding of dressed stone upon each other, which is given by various authorities as from 31° to 35° is taken at 32° $\therefore$ tan $\varphi = 0.625$.

§ 17. For economy of material, the wall should approach in section to the wall of uniform stability, which is triangular. In this case. such a wall would have a face batter, of which tan $\alpha = 0.687$.† On the other hand, on account of practical difficulties of construction, the value of $\alpha$ should not exceed the limiting angle of sliding of stones on moist mortar.

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* Van Buren, LVII. Transactions (20).

† Rankine's Applied Mechanics, § 216. Equation (14).

Some experiments give this angle at 22°. The angle adopted for the wall is 21° 49′, or tan $\alpha = 0.4$.

§ 18. The condition of frictional stability for the wall is tan $\Theta <$ tan $\varphi$, $\varphi$ being taken at the limiting angle for dressed uncemented stone; if $\Theta$ is made equal to $\varphi$ for a cemented wall, the adhesive power of the mortar is amply sufficient to produce the required inequality; we have therefore tan $\Theta = 0.625$.

§ 19. The equation of stability of position (*i.e.*, against overturning) for a wall of this form is*

$$W(q \pm q^1)\ b = \frac{h^3}{6}$$

Substituting the values of the factors as given in § 14, and reducing, we obtain for top width of dam

$$a = \frac{h}{2}\left(\frac{1}{6\ tan.\ \Theta} - tan.\ \alpha\right) \therefore \text{ in this case } a = 0.1433\,h.$$

For different heights of dam, the values of $a$ to fulfill the conditions of stability are therefore:

| $h$. | $a$. | $h$. | $a$. |
|---|---|---|---|
| 10 | 1.43 | 40 | 5.73 |
| 20 | 2.86 | 50 | 7.16 |
| 30 | 4.30 | 60 | 8.60 |

§ 20. As built, $a = 8.6$ for so much of the dam as lies between the points where the plane of the stream level intersects the slope of the hills. Between those points and the extremities of the dam, as $h$ diminishes rapidly, the same width of dam at top would give an unnecessary excess of material. At the same time, a less value of $a$ than 5 feet is not advisable, that being the thickness of the two facing walls, and the least that is efficient for water-tight work. The top width of the dam is therefore reduced between the points above mentioned and the ends of the dam, by deflecting the line of the vertical face until it is 5 feet from the front angle at the ends of the dam, the line of the front angle being straight, and the sloping face a plane surface throughout.

§ 21. Below the level of the stream, the width of the masonry was increased 1½ feet on each side, and the foundation carried to the rock with a slope on each face of 1 to 2.

§ 22. As originally designed, the waste water from the reservoir when full, was intended to flow over the top of the masonry at the north-east end of the dam, the masonry there being left lower than on the rest of the wall. The overfall was arranged in three sections, one at the extreme

* Rankine's Applied Mechanics. § 216 (2 A).

end cut in the rock, 30 feet long at flow line elevation, the second 9 inches higher, over the masonry and 100 feet long, and the third, 1½ feet above flow line, and 70 feet long. The rock at the base of the face wall for 220 feet at this end to receive the base stones, was cut in steps, level on the face and sloping back at the angle of the wall.

§ 23. For drawing off the water in the reservoir, two water ways, each 4½ feet in diameter, were built through the dam at stream level, as shown in the Plate. Grooves for stop plank were arranged on the up-stream face of the dam, and cast-iron gates with composition facings were intended to be placed in a gate-house fitted for the purpose on the lower side.

§ 24. An earth embankment was built against both sides of the dam to 10 feet above the stream level. To prevent percolation of water through the masonry, it was intended that the joints on the up-stream side of the wall should be raked out, and then thoroughly calked and pointed with cement.*

§ 25. In 1870 when the dam was nearly completed, the control of the work was transferred by the organization of the city government under the charter of April, 1870, to a Department of Public Works, which took the place of the Croton Aqueduct Board.

§ 26. The new authorities made the following changes of plan :

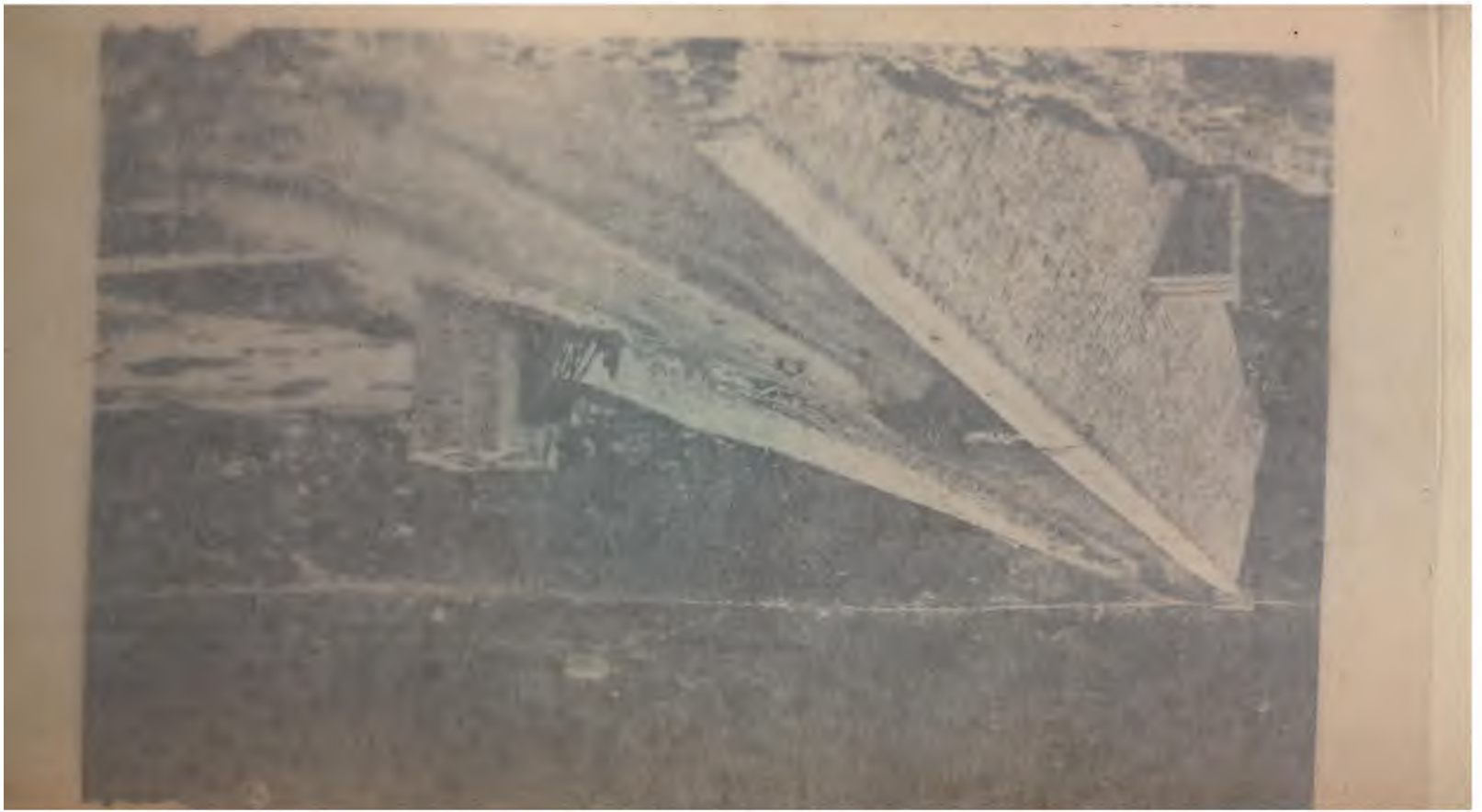
1st. On the water side of the dam an earthen embankment was built, 20 feet wide on top, and with slope of 5 to 2.

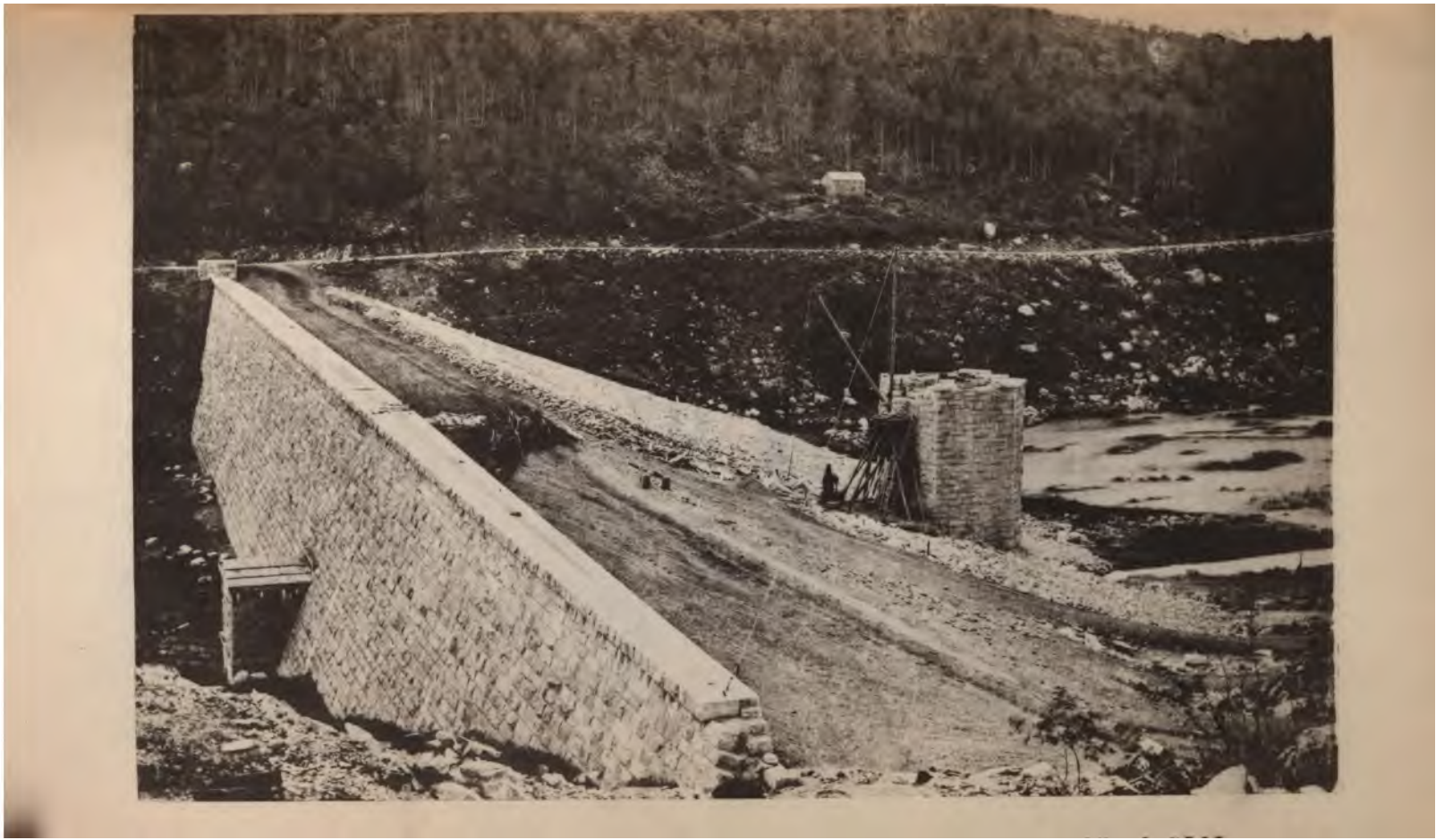
2d. At the foot of this slope a tower of masonry was built to above the water level. From the tower, in which are grooves for stop-plank, two lines of 36-inch pipe were laid underneath the embankment, and through the water ways, and carried several hundred feet below the dam. Stop-cocks were placed in a vault built against the upper face of the dam.

3d. An excavation was made in the rock at the north-east end of the dam, about 100 feet in width, for the waste way.

§ 27. By the construction of the earth embankment, the masonry dam is changed into a retaining wall, which is impervious, and sustains a bank of earth exposed to saturation. If there could be any certainty that the embankment was impervious to water, the stability of the wall would not be endangered. But the embankment was built upon the original porous gravel, 20 feet in depth, extending entirely under the

* The dam was designed and the specifications prepared by Gen. George S. Greene, Engineer-in-Charge.





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bank to within a few feet of the dam; it was built by contract, and not rolled nor thoroughly rammed, but merely carted over. The material is not such as to "puddle" well. It is therefore extremely improbable that the portion adjoining the dam will be secure from the infiltration of water falling on its surface, or the penetration of the water from below, under 60 feet head in the reservoir.

§ 28. If it is saturated, the pressure against the wall is equivalent to that of a fluid of the same specific gravity as the earth. If this is taken only as 1.60, the value of tan $\Theta$ becomes at the bed joint (60 feet below top of dam) = 0.996, and the resultant of pressures strikes the base only 1.1 feet inside the edge, making $m = 0.034$, showing that instead of a dam amply strong to resist any pressure of water, the wall has become a retaining wall so near the limit of stability as to be, if not unsafe, at least very imprudent. Its stability now depends *entirely* upon the adhesion of the mortar, for the embankment is not water-tight, and the face of the dam is constantly wet with water which has percolated the masonry for want of calking to the joints on the upper face.

§ 29. The position of the line of resistance in the dam as built to resist a water-pressure, is shown in Fig. 2. The values of $\sigma$. *tan.* $\Theta$ and $m$ for every 3 feet in height, are as follows:

| | Specific Gravity of the Mass. | Distance of the centre of Resistance from the outerEdge of Base | Condition of frictional Stability, *tan.* $\Theta <$ 0.625. | Condition of Stability of Position $m >$ 0.25. | | Specific Gravity of the Mass. | Distance of the centre of Resistance from the outerEdge of Base | Condition of frictional Stability, *tan.* $\Theta <$ 0.625. | Condition of Stability of Position $m >$ 0.25. |
|---|---|---|---|---|---|---|---|---|---|
| | | | Actual Values. | | | | | Actual Values. | |
| *h.* | $\sigma$ | $m\ b.$ | *Tan.* $\Theta$. | $m$. | *h.* | $\sigma$ | $m\ b.$ | *Tan.* $\Theta$. | $m$. |
| 3 | 2.483 | 5.12 | 0.065 | 0.523 | 33 | 2.343 | 8.66 | 0.463 | 0.398 |
| 6 | 2.461 | 5.82 | 0.124 | 0.529 | 36 | 2.334 | 8.73 | 0.488 | 0.380 |
| 9 | 2.442 | 6.41 | 0.177 | 0.526 | 39 | 2.328 | 8.78 | 0.511 | 0.363 |
| 12 | 2.418 | 6.91 | 0.226 | 0.516 | 42 | 2.321 | 8.80 | 0.532 | 0.347 |
| 15 | 2.410 | 7.33 | 0.268 | 0.503 | 45 | 2.314 | 8.80 | 0.552 | 0.331 |
| 18 | 2.397 | 7.68 | 0.308 | 0.486 | 48 | 2.322 | 8.80 | 0.568 | 0.316 |
| 21 | 2.384 | 7.97 | 0.344 | 0.469 | 51 | 2.328 | 8.78 | 0.583 | 0.300 |
| 24 | 2.372 | 8.21 | 0.378 | 0.451 | 54 | 2.333 | 8.76 | 0.597 | 0.291 |
| 27 | 2.362 | 8.40 | 0.408 | 0.433 | 57 | 2.337 | 8.72 | 0.610 | 0.278 |
| 30 | 2.352 | 8.55 | 0.437 | 0.415 | 60 | 2.340 | 8.68 | 0.622 | 0.266 |

Pressure per square inch of wall on foundation 38.4 pounds; result-

ant pressure on foundation 45.25 pounds; and pressure of foundation on rock 38 pounds.

PLANS AND PROPOSALS FOR CONSTRUCTION.—§ 30. The law with regard to work undertaken by the Croton Aqueduct Board required it to be let at public competition to the lowest bidder. On August 20, 1866, eight proposals were received and opened. The following were the prices offered:

| | No. of Bid | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| | Class of Work. | | | | Prices | | | | |
| A | Earth Excavation below stream, per cubic yard | $1.00 | $1.00 | 2.60 | $0.75 | $2.00 | $1.00 | $1.35 | $2.00 |
| B | Earth excavation above stream level per cubic yard | 0.50 | 0.25 | 0.90 | 0.45 | 0.75 | 0.50 | 1.35 | 0.50 |
| C | Rock excavation, per cubic yard | 10.00 | 2.00 | 3.00 | 0.50 | 2.50 | 5.00 | 4.60 | 5.00 |
| D | Dimension cut stone masonry, per cubic yard | 30.00 | 60.00 | 78.84 | 27.00 | 40.00 | 108.00 | 66.66 | 40.00 |
| E | Cut range masonry, per cubic yard | 15.00 | 25.00 | 21.75 | 20.00 | 12.00 | 27.00 | 47.00 | 22.00 |
| F | Rubble range " " " | 11.00 | 14.00 | 17.00 | 11.93 | 9.00 | 10.00 | 40.00 | 18.00 |
| G | Concrete masonry below stream level, per cubic yard | 8.00 | 7.50 | 6.60 | 9.93 | 10.00 | 10.00 | 11.45 | 17.00 |
| H | Concrete masonry above stream level, per cubic yard | 6.50 | 7.00 | 6.10 | 7.93 | 8.00 | 10.00 | 11.45 | 16.00 |
| I | Flagging for gate-house roof, square foot | 0.20 | 1.00 | 0.60 | 2.00 | 0.30 | 2.00 | 2.40 | 1.35 |
| J | Earthen 9-drain pipe, linear foot | 1.00 | 2.00 | 1.00 | 5.00 | 2.50 | 2.00 | 2.27 | 4.00 |
| K | Cutting grooves for gates, per square foot | 0.30 | 1.00 | 1.27 | 3.00 | 1.50 | 2.00 | 3.77 | 0.60 |
| L | Brick masonry in arches, per cubic yard | 20.00 | 20.00 | 22.00 | 20.00 | 20.00 | 27.00 | 36.67 | 28.00 |
| M | Temporary road, per rod | 10.00 | 10.00 | 5.00 | 5.00 | 8.00 | 10.00 | 6.37 | 3.00 |

§ 31. A comparison of these bids is instructive, as showing the different manner in which contractors interpret plain specifications, and the variety of views entertained as to the proportions of remunerative and unremunerative work in an undertaking of this size.

§ 32. "*A*. For Earth Excavation," including all material except solid rock which required blasting, and boulders of more than one-half a cubic yard content, from the dam site below the level of the stream, and including the cost of putting the same in embankment or spoil bank, and all pumping and bailing for keeping the pit free from water.

| Bid No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Price, per cubic yard | $1.00 | $1.00 | $2.60 | $0.75 | $2.00 | $1.00 | $1.35 | $2.00 |

In these figures is seen the effect of the unknown constant for pumping and bailing. The plan for the work required the stream to be diverted from its channel near the centre of the valley, and a new channel made about 100 feet to the north-east, an embankment 10 feet above the ordinary stream level to be built around the pit on the south-west, and the excavation within this bank to be removed down to the rock. Slopes of 1 to 1 were estimated to the contractor, all caves and slides beyond that to be at his own cost.

The amount of water which might be expected to percolate the gravel was estimated by the various bidders at very different figures, their bids showing that it was considered to be worth from $0.35 to $1.70 per cubic yard of earth to take care of the water. The actual cost of the removal of water from the pits during excavation was about 45 cents per cubic yard of excavation.

§ 33. "*B.* For Earth Excavation" above the level of the stream, including everything as specified under "*A.*"

| No. of Bid | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Prices, per cubic yard | $0.50 | $0.25 | $0.90 | $0.45 | $0.75 | $0.50 | $1.35 | $0.50 |

Of these figures, No. 2 is unaccountable and displays great lack of judgment. The excavation for the dam proper was in shallow pits, on a steep hill-side and of very hard material. It was known to be likely that the estimated quantity would be increased for embankment around the dam, the material for which would require to be selected, and to be hauled not less than 1,200 feet, and well compacted in bank. Instead of following the rule, which almost invariably holds good, that for an item which is likely to be increased, a good paying price should be offered, this bidder reduced his price on this item to less than cost. No. 3 exaggerated the cost of this work as he did of the pumping, and No. 7 evidently did not intend to lose on either "*A*" or "*B.*"

§ 34. "*C.* For Rock Excavation," requiring blasting, including the removal of all boulders of over one-half a cubic yard content.

| No. of Bid | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Price, per cubic yard | $10.00 | $2.00 | $3.00 | $0.50 | $2.50 | $5.00 | $4.60 | $5.00 |

The estimated amount of rock was not large, and No. 1 evidently counted on its increase. The event proved him to be right, and this item alone compensated him for a large proportion of his losses on other items. The excavation contained from 7 to 14 per cent. of boulders of over one-half cubic yard, and it was necessary to take out a considerably larger amount of rock on account of seams and shakes than the test pits gave

reason to anticipate. But No. 4, which was made by a contractor of large experience is unaccountable, except on the supposition that the bidder assumed that all the rock would be in the form of boulders of from one-half to one cubic yard content and easily handled.

§ 35. "*D.* For Dimension Cut Stone Masonry," every stone to be cut to exact dimensions; the beds and joints dressed to lay ½-inch joints, and the exposed faces hammered down to an even surface.

| No. of bid | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Price, per cubic yard | $30.00 | $60.00 | $78.84 | $27.00 | $40.00 | $108.00 | $66.66 | $40.00 |

In this and the following masonry items, the prices offered vary with the previous experience of the contractor. No. 1 had never done similar work. Nos. 4 and 5 had never done work for the Croton Board, but were accustomed to railroad work. Nos. 2 and 3 had done some similar work for the Croton Board, and No. 6 had done a large amount of precisely similar work. No. 7's prices were high throughout. No. 8 was an engineer, who ought to have known the cost of such work better. The estimated quantity was small.

§ 36. "*E.* For Cut Range Masonry."—Certain portions of the masonry around the gate-house were specified as coming under this head; the beds to be cut to lay ¾-inch joints throughout, and the end joints for 18 inches from the face; the face to be pointed down to ½-inch projection, with a chisel draft around the arris.

| No. of bid | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Price, per cubic yard | $15.00 | $25.00 | $21.75 | $20.00 | $12.00 | $27.00 | $47.00 | $22.00 |

§ 37. "*F.* For Rubble Range Masonry."—The face walls of the dam were specified as to be of this class. The setting-bed to be cut to lay ¾-inch joint throughout, and the ends and top for 12 inches back from the face; the rise of the stone to be not less than 12 inches, and the beds from 2½ to 4 feet; the face to be rough, with line pitched at the arris.

| No. of bid | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Price, per cubic yard | $11.00 | $14.00 | $17.00 | $11.93 | $9.00 | $10.00 | $40.00 | $18.00 |

One important reason for the discrepancy in the prices on this item, was the title adopted in the specifications. *Rubble range* was not an ordinary term for any class of cut stone masonry, and while the specifications distinctly described the work, and the portions of the dam where it was to be used, the use of the word *rubble* appears to have produced an impression on the minds of some of the bidders, that it was to be *random* work, laid up without regular courses. It was in fact, however, laid in courses, extending the length of the dam, the rises varying from 14 to 26 inches, and averaging 21 inches.

It was afterwards stated by some of the bidders that they had intended contesting the classification of this masonry, and that they expected to be able to procure its being rated as "Cut range," and therefore had bid a low price for it. This practice of *gambling on items* is inseparable from the method of letting work at public competition to the lowest bidder. The only protection the engineer has, is to make the specification so distinct that no question can arise as to the classification of work. In the specifications for the dam, the description of this class of work is so explicit, that no claim for payment for it under any other classification, has been or can be allowed.

It might have been better if the word rubble had been omitted, as that appears to be the only basis for any misunderstanding.

§ 38. "*G.* For Concrete Masonry" laid below the level of the stream; stone to be broken to not more than 2 inches in its largest dimension, nor less than ½ inch in its smallest. Mortar to be composed of one part of hydraulic cement to two parts of sand, by measure; the proportion of mortar to stone to be such as to fill all void spaces, and be in excess of the same not more than ten per cent. The concrete to be laid in courses of 6 inches, and well rammed. In the concrete, and to be measured as part of the same, it was permitted to lay large unwrought stones. These stones to be laid in full beds of mortar, and the surface covered with mortar ½-inch thick immediately before laying concrete around them. The price for concrete to cover all expense of bailing and draining:

| No. of bid | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Price, per cubic yard | $8.00 | $7.50 | $6.60 | $9.93 | $10.00 | $10.00 | $11.45 | $17.00 |

§ 39. "*H.* For Concrete Masonry" laid above the stream level. The specifications the same as for "*G.*" This concrete to be inclosed between the rubble range walls. The large stones inserted, to average 5 feet in length and 2 square feet in cross section, and to be laid in layers alternately parallel and at right angles to the walls of the dam.

| No. of bid | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Price, per cubic yard | $6.50 | $7.00 | $6.10 | $7.93 | $8.00 | $10.00 | $11.45 | $16.00 |

The difference between the prices for "*G*" and for "*H*" is due to two causes. In laying "*G*," pumping and bailing would probably be needed. This would increase its cost. On the other hand, the larger area to be covered, and the freedom from the obstruction and interference caused by the laying of the cut stone facings ought to reduce the cost of laying the lower concrete, and the additional hoist, as the masonry rose above the surface of the ground, ought to increase the cost of the concrete

above stream level. Two of the bidders estimated that these variations would counterbalance each other. The others considered that the concrete below stream level was worth from $0.50 to $2.00 per cubic yard more than that above. Actually the cost of pumping chargeable to concrete was equivalent to about 18 cents per cubic yard of that below—and the hoisting to about 8 cents per cubic yard above—the stream level.

§ 40. The provision permitting the insertion of large unwrought stone caused variations in the estimates. In the absence of data, as to the proportion which the stone could bear to the mass, some of the bidders assumed that from two-thirds to three-fourths of the mass would be of stone, which only required to be quarried, and could be set very quickly. In practice it was found, however, that not more than one-third of the mass could be made of the large stone. It was necessary that the stones, should be far enough apart to allow the concrete to be thoroughly spread and rammed between them. This requires a space of not less than 12 inches between the nearest points, and with irregular stones the average distance is greater than this. When stones of irregular heights were laid, the leveling up necessary to prepare for a fresh layer of stone made the mean depth of concrete between the layers probably nearly 12 inches.

§ 41. The next three items, "I," "J" and "K," are for small quantities of special work, and the bids are not worthy of particular consideration, most of them having been made apparently at random, without regard to the cost of the work.

§ 42. "*L.* For Brick Masonry in Arches" of water-ways and gate-house. This item, of some 20 cubic yards, was the only one on which the bids varied less than 200 per cent.

§ 43. The contract, as awarded at this time, was for the construction of the dam to within 30 feet of the top. The appropriation authorized was not sufficient for the completion of the whole dam, and the law forbade any contract to be made in excess of the appropriation. Further expenditure was authorized subsequently, and the upper 30 feet of the dam was built under a new contract, made with the same parties that built the lower portion.

Progress of Construction.—§ 44. Work was begun in September, 1866. A new channel was made for the stream near the base of the North-east Hill, an embankment built around the remainder of the dam site, on the flat ground, and carried up 10 feet above the stream level. The pit within this embankment was partially excavated, the material

being deposited below the dam. The quarrying and cutting of stone was begun, and a Blake's stone-breaker put in operation. On October 29th–30th, 3.91 inches of rain fell in 10 hours, causing a heavy freshet which washed away the contractor's bridges, filled the pits with water, and cut embankments badly. After pumping out the pit, the excavation was continued until December 21st, when the pit was allowed to fill.

§ 45. Some observations of work done in bailing from a pool into a trough 4 feet above the water, showed that the average work per minute, of a man was 12 bucketfuls, equivalent to about 1,200 pounds of water 1 foot high.

§ 46. The winter was devoted to quarrying and breaking stone. Some cement was delivered, but was found not to be equal to the requirements of the specifications. A cargo of 900 barrels was rejected, and the delays and discussions consequent upon this prevented the receipt of any more cement until spring.

§ 47. The great distance of the work from any rail or water transportation was a serious drawback. The nearest point to which supplies could be brought by water was 16 miles distant, and over a very bad road. The nearest foundry and machine-shop was at the same distance. The nearest railroad station was 8½ miles distant, on the Harlem Railroad.

§ 48. Sand, of proper quality, was difficult to get. All the bank sand within many miles was tested and rejected as containing too much dust and loam. The only sand found at all admissible was procured from the bed of the stream, in pools where the flow was sluggish and the sand had settled. Most of this was of good quality, but some was very dirty and had to be washed, and all of it had to be screened to remove chips and coarse material. From beginning to end of the construction of the dam there was a continuous struggle on the part of the engineer to have the sand for mortar properly cleaned and screened, and of the contractor to avoid it. That sand should be sharp, clean, and screened to proper size, is absolutely essential to good mortar, and there is no point on which, as a general thing, contractors and builders are so lax. Several methods of washing were tried, of which the most successful consisted in spreading the sand in a layer of about 3 inches in depth on the bottom of a shallow box, 6 feet by 12 feet, slightly inclined, and playing upon it with a hose from a force-pump. With proper manipulation the sand was pretty thoroughly cleaned. The process was expensive, however, and after one or two loads were operated on in this way, the sand would come to the work much cleaner.

§ 49. In the spring of 1867 the main pit was pumped out, and excavation continued. The engine and boiler of 15 horse-power used for running the stone-breaker, were placed on the embankment above the pit, so as to operate a hoisting drum and an Andrew's pump throwing an 8-inch stream. After the pit had been once emptied, the pumping did not need to be continuous. The engine was able to hoist material from the pit, and at the same time either pump or break stone, but not together.

§ 50. North of the stream the foundation for the gate-house was prepared. On the side towards the stream, a trench 3 feet wide and 4 feet deep, was dug to the rock and filled with concrete, as a temporary dam to keep water from the gate-house pit. This concrete was made with 24 feet of broken stone to 1 barrel of cement and 2 of sand, and was deposited gently in the still water which filled the trench. It was not rammed, but the wet mass was worked down with shovels. One year afterwards, when this concrete was removed to make the connection with the gate-house, it was found necessary to drill and blast it. It had formed a good bond with the rock, and apparently no water had passed under it.

§ 51. The first stone of the dam was laid July 9th, 1867, in the gate-house foundation, and concreting was begun in the main pit, July 11th. During the rest of the season the foundation in the main pit was raised to the stream level, and the masonry of the gate-house and waterways was carried up 8 feet. The side of this, towards the stream, was built vertically, the concrete being put in against plank forms. On the removal of this during the following year, the face of the concrete was found good. To connect the new work with it, and avoid a straight joint through the dam, two vertical channels were cut in the concrete, 3 feet wide and a foot deep. These were cut by a stone-cutter, with a point. A pick made no impression on the concrete.

§ 52. Masonry was suspended November 5th, and the concrete already laid, covered with 2 feet of earth to protect it from frost. Some rubble masonry was laid after that date in wing walls adjoining the waterways above and below the dam. In freezing weather the mortar was mixed with salt-water. The rule for proportion of salt was one said to have been used in the works at Woolwich Arsenal some years ago, viz. ; dissolve 1 pound of rock-salt in 18 gallons of water when the temperature is at 32° Fahr., and add 3 ounces of salt for every 3° lower temperature. The masonry laid with mortar thus prepared stood well, and

In the spring of 1867 the main pit was pumped out, and exca-
The engine and boiler of 16 horse-power used for
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FOUNDATION OF DAM. SEPTEMBER 1867. LOOKING NORTH-EAST.

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TILDEN FOUNDATIONS

showed no signs of having been affected by the frost. No masonry in the dam was laid in freezing weather.

§ 53. The ensuing winter was very cold and stormy. Quarrying, cutting and breaking stone were carried forward, and sand and cement hauled. The water of the stream was carried through the gate-house.

§ 54. Work on masonry was resumed March 30th, 1868. The first part of the season was wet. A very heavy freshet occurred May 14th. The water rose 3 feet on the masonry laid in gate-house, and filled the pits. The latter part of the season was very dry, however, and the whole dam was raised 16 feet above the stream. Work was closed November 17th, and the masonry covered as before with 2 feet of earth.

§ 55. During the latter part of this year's work it had become evident that the insertion of large stone in the concrete was not beneficial. The space between the side walls was becoming narrow; at the close of work it was 21 feet. The dam was 400 feet long and 6 feet above the earth filling. It was no longer practicable to wheel the concrete from the mixing boards in barrows, but it had to be hoisted by derricks and transported by cars. When a course of facing-stone had been laid, and the space between them was to be filled with concrete, and that was filled with irregular shaped stones 1½ or 2 feet apart, it was difficult to get an even bearing for run plank and almost impracticable for a tramway. The odds were greatly against the concrete around these stones being properly distributed and rammed, if it was dumped from a car. Even when distributed by the barrow-full (2 cubic feet), it required constant attention and no small amount of persistence to secure its being spread in the narrow spaces. The stone in the vicinity of the dam which was fit for cutting had been pretty thoroughly used up, and it was questionable whether a sufficient quantity to finish the dam could be procured at all, if 3,000 additional cubic yards were put in the hearting. The scarcity of good stone caused a constantly increasing tendency on the part of the contractor to run in and cover up weather-beaten stones which were unfit for the work, on account of the impossibility of the mortar adhering properly to the weather face. It had several times occurred that such stones were brought in, and a little grout poured over them to hide the deficiencies, and very probably more of the same kind were never discovered. It was questionable, moreover, whether so great solidity and tightness could be obtained by a wall of large stones, surrounded by thin masses of concrete, as by a thick mass of concrete alone. After full discussion of the subject, it was determined to abandon for the rest

of the dam the use of the large stone, and use only concrete for the hearting. These objections to a wall of concrete and large rough stones apply mainly to thin walls, say of less than 10 feet in thickness, intended to resist water. A wall of this class may be laid to advantage when over 10 feet thick, but the stone should be required to be regular in shape, of not more than 18 inches height, and no stones should be allowed to be less than 2 feet apart. By their use under these restrictions, the specific gravity of the wall may be increased and its cost diminished, and with a much greater certainty of getting good work and tight, than if the wall is laid up with rubble masonry.

§ 56. The laying of masonry was resumed June 23d, 1869, and continued until November 1st, when the wall had reached an elevation of 38 feet above the stream. The masonry was again covered with earth 2 feet thick, which was found to protect the concrete from frost quite well. In some places it was necessary to remove from 2 to 3 inches of the old work in the spring. The winter was devoted as usual to quarrying, cutting and breaking stone. Enough broken stone was prepared to finish the dam.

§ 57. Work on masonry was resumed, April 13th, 1870, and the dam, as originally designed, was completed by November 1st, 1870. Owing to the changes of plan mentioned above, the reservoir was not ready for use until the fall of 1872. The dam contains, approximately, 21,000 cubic yards of concrete, and 6,000 cubic yards of cut stone masonry.

General Methods of Handling Materials.—§ 58. No expensive plant or machinery was used. The buildings were a contractor's office and cement house on the flat below the dam, stables and blacksmith shop near by, and a shed for stone-cutters on the flat above the dam. The stone yard was just above the dam on the north-east side of the stream. The stone for cutting and breaking for the first two years was procured from the hill-side, within 1,000 feet of the yard, and from 50 to 300 feet above it. The third year the haul was about 2,000 feet, and the last year most of the stone for cutting was hauled 2 miles. From the neighboring hills, the stones were transported on stone boats, with oxen. For long hauls, low trucks were used, the stone being first brought to the road on stone boats. When the hill-sides were dry and rocky, the wear of stone boats was enormous. For transporting the cut stone from the yard to the work, trucks drawn by horses, were generally used, depositing the stone within reach of a derrick on the work. In the main pit a double-geared derrick, with 50 feet boom, was at first used

for setting stone. Its great weight made it unwieldy, and for the last two seasons derricks of 30 feet mast and 25 feet boom were used. These could readily be shifted and raised. A heavy block, with a socket for the pin at the foot of the derrick, was laid on the concrete, and boards around it for the hoisters to stand upon. The derricks were worked by hand until the masonry was 10 feet above the bank. After that 2 steam hoists were used, a vertical 8 H. P. engine, with drum, being placed on the lower side of the dam, and the fall brought to it over the edge of the masonry. All the material to be hoisted was delivered under the boom on the vertical side of the dam.

§ 59. Below the embankment level, the sand and cement for mortar were mixed dry on the bank, and sent into the pit by a shute, to the mixing board. The broken stone was sent down another shute and measured below. From the mixing board it was transported to place in barrows. When the masonry had reached a height of 6 feet above the bank, the mixing platforms were placed on the bank close to the vertical wall, the concrete shoveled from the board into boxes, which were hoisted, placed on a dumping car, running on a track of scantling resting on notched ties laid on the concrete, and wheeled to place and dumped. The track was carried along on top of the new work. As the concrete was dumped from the car, it was leveled off to about 8 inches thick and rammed. From two to three layers, according to the thickness of the course of the face walls, were put one over the other. With the track in the centre of the wall, a width of 20 feet could easily be carried forward, the car being arranged to dump in any direction. The plan worked pretty well, but was a little expensive for the contractor, as the ties became more or less imbedded in the soft concrete, and consequently there was more loose stuff to be removed in preparing for another course than if no traveling over the fresh work had occurred. Boards laid along the track, for the car-tenders to walk upon, protected the green concrete.

Stone for masonry was hoisted in the same way, and carried to the setting derricks, which were worked by hand, the reach of the boom being regulated by the topping lift, and, of course, being altered for every stone that was set. The courses were laid from one end of the dam to the other, so that, while one hoister was raising stone, the other was raising concrete for filling the space between the stones already laid at the other end of the dam.

§ 60. The stone breaker was at first placed on the bank above the

dam, and the broken stone passed from it to the meadow at the stream level. This arrangement was necessary so as to utilize the engine for pumping, but had the disadvantage of causing the stone to be hauled up again from the meadow. After pumping was no longer necessary, the breaker was placed on the hillside in such a position that it was fed from the quarry direct, and delivered stone a little above the level where it was needed, making all the haul descending.

§ 61. Wire guys were used on the derricks, and for a part of the time, when the steam hoist was used, the falls were of annealed wire rope. This generally worked well, but had one disadvantage; it would sometimes break suddenly, without warning, and it took longer to repair than rope.

§ 62. All arrangements for transportation and hoisting were under the contractor's direction, the engineer only seeing that nothing should be done in a manner detrimental to the work.

Character and Cost of Materials.—I. Cement.—§ 63. The specifications required that all cement should be of the best quality of American hydraulic, and subject to such tests as the engineer might direct. For this work it was not so essential that the cement should be quick setting, as that it should be strong. For concrete, a quick setting cement is not to be preferred.

The first cement delivered in October, 1866, contained a considerable amount of coal dust, was apparently not thoroughly calcined, and, when sifted, 22½ per cent. by weight would not pass through a sieve with openings of $\frac{1}{40}$th inch. The cargo was rejected. The contractors claimed that they could not procure any better cement. All of the Rosendale works were visited, and only one company would agree to furnish a cement which should contain less than 15 per cent. of matter coarser than $\frac{1}{40}$th inch. The other companies said they had a ready sale for any cement they offered, and would not go to additional expense and trouble to grind the cement finer. The company which consented to make an effort to improve their cement furnished nearly all that was used on the dam, and, out of a great many samples tested for fineness, only three were found to equal the limit assigned. In 1869–70, samples of several different cements for sale in the New York market were tested with the results shown in the following table. Different brands are designated by different letters. "B" was the cement used on the dam.

§ 64. Tests of the tensile strength were made. The blocks had a sectional area of 2¼ square inches, with shoulders for clamps. They were

mixed in moulds, immersed in water for twenty-four hours, and broken after having stood for from seven days to a year and a half. No practical use was made of these tests at the time. The results of a large number are given in the table :—

| | Fineness. Percentage by Weight. | | | | | Tensile Strength. Lbs. pr. sq. inch. | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Brand. | Over 40. | 40 to 80. | Brand. | Over 40. | 40 to 80. | Brand. | 7 days. | 21 days. | 3 mo. |
| 1867. | A.... | 22.5 | 7.5 | C.... | 19.4 | 11.2 | A..... | 32 | 94 | 111 |
| | A.... | 16 | 11 | C.... | 26.3 | ..... | B..... | 49 | 111 | ..... |
| | B.... | 15 | 11 | D.... | 15.9 | 11.1 | B..... | 61 | ..... | 135 |
| | B.... | 14 | 11 | E.... | 15.4 | 10.9 | B..... | 61 | 84 | 100 |
| 1868. | B.... | 7.4 | 11.1 | F.... | ..... | ..... | B..... | 58 | 101 | ..... |
| | B.... | 10 | 13.7 | G.... | 22.8 | ..... | B..... | 56 | 63 | ..... |
| | B.... | 12.5 | 13.7 | H.... | ..... | ..... | B..... | 50 | 66 | ..... |
| | B.... | 6.6 | 8.4 | I.... | 28.8 | ..... | C..... | 37 | 66 | 75 |
| 1868. | B.... | 4 | 6 | J.... | 7.5 | ..... | D..... | 48 | 82 | 82 |
| | B.... | 20 | 5.0 | K.... | 20 | ..... | E..... | 59 | 62 | 73 |
| | B.... | 6.6 | 4.1 | L.... | 18.8 | ..... | F..... | 55 | 62 | ..... |
| | B.... | 9.4 | ..... | ..... | ..... | ..... | G..... | 66 | 94 | 99 |
| | B.... | 15 | 6.9 | ..... | ..... | ..... | H..... | 28 | 65 | 95 |
| 1869. | B.... | 10 | 5.3 | ..... | ..... | ..... | I..... | 26 | 59 | 72 |
| | B.... | 8 | 4.7 | ..... | ..... | ..... | J..... | 54 | 80 | 87 |
| | B.... | 6.2 | 4.7 | ..... | ..... | ..... | K..... | 35 | 69 | 77 |
| | B.... | 8.1 | 5.6 | ..... | ..... | ..... | L..... | 26 | 74 | 84 |

§ 65. An analysis of the whole series of experiments appeared to establish these facts :—

(a.) The average tensile strength per square inch at the end of seven days, of cements, of which less than 10 per cent. by weight was over $\frac{1}{10}$th inch diameter was 54½ pounds, while that of those of which more than 15 per cent. was over $\frac{1}{10}$th inch diameter, was 39 pounds.

(b.) When cements containing from 10 to 23 per cent. of particles over $\frac{1}{10}$th inch diameter were sifted through a "40" sieve, the tensile strength of the fine portion was 20 per cent. greater than that of the cement before sifting; but in cements containing from 23 to 30 per cent. of the coarser particles, the removal of those particles reduced the tensile strength of the cement about 25 per cent.

(c.) The tensile strength of the cements increased continuously for 9 months. Reliable observations for longer periods were not obtained. The maximum results were :—

| Time..... | 7 days. | 14 days. | 21 days. | 3 mo. | 6 mo. | 9 mo. |
|---|---|---|---|---|---|---|
| Pounds per square inch..... | 86.5 | 89 | 111 | 155 | 222 | 250 |

(d.) The cements which gave the best results at seven days generally maintained their superiority throughout.

§ 66. Some of the cements used which set quite slowly at first, made exceedingly hard concrete. The most compact concrete which was cut into at any time was made with a lot of cement which barely escaped condemnation on account of its setting so slowly. No samples of the brand used refused to set under water.

§ 67. A systematic testing of *all* the cement used on a work situated as this was, is very difficult. From 2,000 to 3,000 barrels were used in a month, and it sometimes happened that, owing to delays in transportation, all the cement used for several days in succession was delivered directly at the concrete boards by the teams which hauled it from the railroad. It is due to the cement company which furnished the cement to say that it was generally very satisfactory. The difficulty with most of the cement companies now is, that during the summer their works are taxed to their utmost capacity to supply the market, and, in ordinary building, almost anything which bears the Rosendale brand is accepted without question, so that there is no inducement for them to take any pains to improve the quality of their cement. The experience of Mr. Shedd on the Providence (R. I.) sewers shows, however, that it is not only practicable to make tests of all cement used on a large work, but to raise the standard of that which is furnished.

The average weight of a barrel of cement used on the dam was 284 pounds net.

II. Broken Stone for Concrete.—§ 68. Stone for concrete was broken to be not more than 2 inches in its largest dimension. A Blake's stone-breaker of 15-inch jaw was used, driven by a 15 horse-power engine. The stone which was obtained from the surface and from old fence walls in the vicinity of the work was tough and used up the jaws very fast. A moveable jaw ordinarily lasted 20 days. On one occasion, a jaw costing $70, and which had been hauled 16 miles over-night and put in the machine in the morning, was so worn by night as to be useless. With chilled jaws and careful handling, and using quarried stone instead of stone from the surface, a pair of jaws lasted much longer on the latter

part of the work. The last pair used broke about 3 000 cubic yards of stone.

As the stone passed from the breaker, it traversed an inclined screen, made of ½-inch iron rods placed parallel, about ¼-inch apart, on a slope of 1 to 1. The dust and screenings were carted away, and the stone wheeled into a pile. One, and sometimes two men were necessary on the dump, to break the larger stone as they were deposited. With a fresh set of jaws no additional breaking was needed, but as they became worn, stone in excess of the proper size would sometimes pass. The stone was delivered to the breaker by carts, having been first sledged to the proper size, about 12 inches square, by 6 inches thick. The machine when running at full speed, with one man feeding, two men supplying him with stone, one keeping the screen clear and helping to fill barrows, two wheeling away the stone and one on the dump, could break 144 cubic feet in an hour, or at the rate of 54.4 cubic yards per day of 10 hours. This excessive speed was kept up, however, only as long as it was known that an inspector was timing it. The average rate of breaking for the last year was 3.8 cubic yards per hour, which may be assumed as the economical rate for the 15-inch machine.

The largest sized machine (20 inches) will break 8 cubic yards per hour if fed to that capacity, but 6 cubic yards per hour is more economical.

§ 69. The cost in time, of breaking stone, was as follows:

| | | | 1867. | 1868. | 1869. | 1870. |
|---|---|---|---|---|---|---|
| Total cubic yards broken | | | 2 410 | 4 170 | 5 720 | 3 650 |
| Number of days | | | 109 | 152.5 | 155.5 | 96 |
| Average cubic yards per day | | | 22.1 | 27.3 | 36.8 | 38. |
| Days per Cubic Yard. | Furnishing. | Laborers sledging | 0.269 | 0.322 | 0.224 | 0.410 |
| | | " loading carts | ..... | 0.051 | 0.042 | 0.087 |
| | | Carts hauling | 0.049 | 0.092 | 0.066 | 0.118 |
| | Breaking. | Engine and machine | 0.045 | 0.037 | 0.027 | 0.026 |
| | | Labor tending machine | 0.360 | 0.238 | 0.158 | 0.174 |

The difference in sledging is accounted for thus:

1867. Many fence wall and cobble stones were used, which needed no sledging, but were hard to break.

1868. Refuse from quarry almost altogether used, which had to be sledged.

1869. Stone yard and quarry spauls used up.

1870. Stone-cutting and quarrying for same, done at a distance, and stone quarried near by for breaker; consequently nearly all stone used was sledged.

The carting varied in the same way for the same reasons.

The tending was greater in 1870 than in 1869, because in the earlier year the breaking covered the working season, during a large part of which the carts hauling stone to the concrete boards took their loads direct from the breaker, while in the winter of 1869–70, all stone broken was wheeled into the pile, the wheelers being reckoned among the *tenders*. The item for engine and machine includes cost of engine driver and helpers, fuel and repairs of engine. In estimating cost of breaking, the repairs and maintenance of stone-breaker must be added. This is worth about 0.05 day laborer per cubic yard.

The stone, when broken, weighed 90.3 pounds per cubic foot, and the void spaces averaged 47.55 per cent. of the bulk.

III. Mortar and Concrete.—§ 70. The mortar made of one barrel of cement to two of sand, measured 9.70 cubic feet per batch. This was the average of a large number of measurements, the extremes varying 7 per cent. each way. While the void spaces of the stone averaged 47½ per cent., there would sometimes be a coarse run of stone which had 53 per cent. of void spaces. To cover such cases, the mortar had to be 54 per cent. of the bulk of the stone. This makes the charge of stone to a batch of mortar 18 cubic feet. The stone was measured in barrels, and at first 4½ barrels, holding 18 cubic feet, was the charge of stone. As it was found after some use of the barrels that they became coated with dust and screenings to such an extent as to considerably diminish their capacity, 5 barrels of stone (which held the proper quantity) was the charge for a batch of concrete.

§ 71. For mixing concrete, platforms 12 by 15 feet, of 1¼-inch plank were used, the plank laid lengthwise in the direction the mixers used the shovel. Planed and matched plank are best, as causing less resistance to the shovel, and less loss of water and cement.

§ 72. The sand was wheeled or carted from the piles and deposited at one corner of the board, and 4 or 5 barrels of cement brought at a time and placed there also, the cart on its return-trip taking away the empty barrels.

The sand and cement mixer, standing in a barrel with both heads out on the corner of the platform, filled it with sand, which, with a twist of the barrel he spread, then opened and emptied a barrel of cement on it, and standing the sand barrel on the pile, filled it again. He then turned the mass over and heaped it in a conical pile.

§ 73. The broken stone was deposited near the platform and washed in the pile by a hose. The stone-man shoveled it into 5 barrels with handles and with holes bored in the bottom, which stood in a row at the edge of the platform, and then poured over each from one to two buckets of water, which drained out through the holes in the bottom.

§ 74. Four "mixers" cast the sand and cement from the prepared pile on the platform so as to form a basin into which from 7 to 10 bucketfuls of water were poured from a tub standing at one end of the platform which was kept constantly filled. As the water was put in, the mixers with the backs of their shovels spread the dry stuff over it, taking care not to let the water break through the ring, and mixed the mass by running their shovels through and turning them, thus making a bed of mortar about 8 by 5 feet and 3 inches thick. On this they emptied the barrels of stone, by upsetting them over the handles, and then scraped up the loose mortar around the edges, throwing it on top.

§ 75. Then standing in pairs opposite to each other at the ends of the pile, they turned the mass outward by running the shovel under the stone and mortar, and turning it on its outer edge and drawing it back with a spreading motion over the turned mass. The opposite mixers worked in until the shovels met and then they returned to the edge again. When the two pairs met in the centre of the board, the concrete was in two piles. The operation was then reversed, and the concrete turned again towards the centre, leaving it in one pile, which was then shoveled into the hoisting box. In the meantime, the sand and stone-men had been preparing their materials for the next batch, to which the mixers proceeded as before. The whole operation was performed in from 8 to 10 minutes. In 1869, a day's work for a gang was fixed at 50 batches of concrete. In 1870, 60 batches were given as a day's work, and the task was accomplished in from 8 to 9 hours, according to the length of travel of the cars, and consequent interval between the delivery of the boxes. The work was very arduous, and none but the most powerful men could stand it. They acquired great skill in the manipulation of the concrete and worked very systematically. Part of the time a fifth mixer

was employed in turning up the edges of the pile and helping in the heavy shoveling into boxes.

During the first two years of the work, when the masonry was below or near the ground-level, the mixers shoveled the concrete into barrows which they wheeled and dumped themselves. They were paid by the day, and no limit as to amount was assigned them.

Two "rammers" took charge of the concrete as it was dumped from the barrows or cars, and spread it and then rammed it with wooden rammers.

§ 76. In the following table is given the cost *in time* of laying concrete for each season separately, and also, for comparison, the cost of laying concrete at St. Louis, Mo., as furnished by Mr. T. A. Meysenburg, when in charge of the construction of a reservoir for the St. Louis Water Works. He explains the greater cost of mixing by saying that laborers will not do nearly the same amount of work in that latitude that they will at the East.

| | N. Y. Storage Reservoir. | | | | St. Louis Reservoir. | | |
|---|---|---|---|---|---|---|---|
| | 1867. | 1868. | 1869. | 1870. | 1868. | 1868. | 1869. |
| Cubic yards laid | 2 715 | 4 082 | 6 206 | 3 720 | ..... | ..... | ..... |
| Proportion of stone to mortar | 1.65 | 1.85 | 1.85 | 1.85 | 2.5 | 2 | ..... |

| Days' work per cubic yard. | Mixed on Level and wheeled in. | | Hoisted by Steam and run on Cars. | | On Level—Wheeled in. | | |
|---|---|---|---|---|---|---|---|
| | From 27 to 10 feet below surface. | From 10 below to 6 feet above surface. | From 6 to 28 feet above surface. | From 28 to 45 feet above surface. | | | |
| Mixers } | 0.223 | 0.227 | 0.145 | 0.121 | 0.603 | 0.537 | 0.399 |
| Derrick and carmen } | ..... | ..... | 0.088 | 0.070 | ..... | ..... | ..... |
| Engine—hours | ..... | ..... | 0.152 | 0.108 | ..... | ..... | ..... |
| Handling sand } | ..... | ..... | 0.065 | 0.071 | .... | ..... | ..... |
| " stone } | 0.161 | 0.114 | ..... | ..... | 0.183 | 0.134 | 0.250 |
| | ..... | ..... | 0.127 | 0.098 | ..... | ..... | ..... |
| Carts | 0.065 | 0.076 | 0.046 | 0.035 | 0.088 | 0.057 | 0.068 |
| Ramming | 0.125 | 0.078 | 0.071 | 0.073 | 0.125 | 0.107 | 0.128 |
| Sand—cubic yards | 0.428 | 0.416 | 0.420 | 0.420 | 0.373 | 0.411 | 0.444 |
| Cement—barrels | 1.446 | 1.420 | 1.425 | 1.428 | 1.259 | 1.394 | 1.500 |
| Stone—cubic yard | 0.888 | 0.946 | 0.946 | 0.946 | 0.926 | 0.826 | 1.111 |

To compare the four years' work, the hoisting must be left out of the account. In the first two years, the mixers did the same work that the mixers and car tenders together did in the last two years. The men handling sand and stone must be taken in connection with the carts, as the transportation from the piles was done by barrows or carts according to the distance from the mixing boards. Calling a cart and driver equivalent to two men, we have, as day's work, per cubic yard :

| | 1867. | 1868. | 1869. | 1870. |
|---|---|---|---|---|
| Furnishing material to mixers | 0.291 | 0.266 | 0.281 | 0.229 |
| Mixing and transporting to place | 0.223 | 0.227 | 0.233 | 0.191 |
| Total | 0.514 | 0.493 | 0.514 | 0.420 |

This shows that the increased charge of stone, and the work coming nearer to the surface, diminished the cost in 1868, but that the change in 1869 to the system of paying for 50 batches as a day's work made a considerable increase in cost for that year, while in 1870, when 60 batches was a day's work, the cost was similarly diminished. One reason for the diminished cost of engine in 1870 was that, when concrete had to be put in, two gangs of mixers were kept going by one engine on short runs of the car.

§ 77. The spreading and ramming cost more the first season than afterwards, because, at the beginning of the work, the concrete was made much less moist than in the succeeding seasons, and the first layer on the rock in the bottom required the closest attention to obtain proper adhesion, and insure the bottom of the course being thoroughly filled with mortar. It was found afterwards that where the concrete was surrounded by large stones, freshly plastered, and the water was confined and prevented from running off, the mass worked better and more easily by being made quite wet. A batch transported from the mixing board to the place where it is to be laid, in one mass, and there dumped and spread to proper thickness (about 8 inches), makes far better and more homogeneous concrete than if moved in small quantities in barrows. There is less loss of mortar and water, less separation of the fine and coarse parts of the batch, and, consequently, less tendency to have part of the concrete honeycombed. When the mortar is quite dry, hard ramming is necessary to consolidate the mass, but it also tends to disintegrate

it the instant that the cement has begun to set, and this is generally before the mass can be thoroughly consolidated. The best method is to have the mortar a little more moist than is proper for masonry, the batch dumped in one mass, leveled off with shovels (the spreader at the same time turning over any irregularly mixed parts), and then slightly rammed with a wooden rammer. Where it comes against walls or forms, it is better to compact it by cutting with a shovel and then slightly ramming, than by attempting to make it solid by ramming alone. The amount of water needed varies with the temperature and condition of the atmosphere. Ordinarily, when the sand is slightly damp, and the stone well washed and wet, the quantity of water used in mixing the mortar should not exceed 3¼ cubic feet per batch.

§ 78. The concrete, when set, weighed 133¼ pounds per cubic foot; its specific gravity was 2.13.

IV. Setting Large Stone in Concrete.—§ 79. The large unwrought stones laid in the concrete, from the foundation to within 45 feet of the top of the dam, were set in full mortar beds, and the surfaces plastered just before concrete was laid around them. The setting was mostly done by laborers, one mason superintending. The cost in day's work per cubic yard was as follows:

| | 1867.* | 1868.† |
|---|---|---|
| Total quantity laid, cubic yards | 1 234 | 2 353 |
| Percentage of whole mass | 32 | $36\frac{6}{10}$ |
| | Days, per cubic yard. | |
| Foreman (mason) | 0.046 | 0.057 |
| Laborers setting | 0.208 | 0.142 |
| " plastering | 0.085 | 0.056 |
| " mixing mortar | 0.078 | 0.083 |
| " at derrick | 0.238 | 0.254 |
| Cement—barrels | 0.283 | 0.299 |
| Sand—cubic yards | 0.084 | 0.088 |
| Stone— " " | 0.897 | 0.892 |
| Transporting stone to the work—teams | 0.160 | 0.073 |
| Laborers loading—teams | ..... | 0.305 |

* Stone lowered average of 20 feet.

† One-half lowered 5 feet; one-quarter swung in level; one-quarter hoisted 6 feet.

The cost of the mass of concrete and large stone, as laid in 1867, was 89½ per cent. of the cost of concrete alone, and in 1868 was 84½ per cent. of such cost.

§ 80. For reasons before given (§ 55) the percentage of large stone in work of this class ought not to exceed 25 per cent. of the mass, in which case the cost of the mass may be safely estimated to be reduced 10 per cent. below concrete cost, and its specific gravity increased 8 per cent.

V. Cut Stone Masonry—Quarrying.—§ 81. The stone for cutting was split out on the hill sides, and hauled to the stone yard near the dam. During the first year the quarry was not well managed, and the cost was too great to be of service for comparison. During the second year, the greater proportion of the stone quarried was for rough stone and for breaking. The cost in time of quarrying the stone not intended for cutting was for 3,400 cubic yards :

| | Days per cubic yard. | | Days per cubic yard. |
|---|---|---|---|
| Foreman | 0.041 | Tool-boy | 0.035 |
| Drillers | 0.339 | Teams | 0.141 |
| Laborers | 0.14 | Labor, loading teams | 0.077 |
| Blacksmith | 0.036 | Tools, powder and fuse, to be added. | |

§ 82. From January, 1869, to July, 1870, 4,000 cubic yards of stone for cutting were quarried. All of this was split out with plugs and feathers, and hauled to the stone yard, an average distance of one mile. The cost in time was :

| | Days per cubic yard. | | Days per cubic yard. |
|---|---|---|---|
| Foreman | 0.114 | Tool-boy | 0.108 |
| Drillers | 0.917 | Teams | 0.620 |
| Laborers | 0.429 | Labor loading teams | 0.284 |
| Blacksmith | 0.102 | | |

VI. Stone Cutting.—§ 83. Rubble range masonry is described above in § 37. The stone was estimated at 2½ feet beds. The actual average bed as laid in walls was 2.715 feet. As estimated, 10.8 square feet of face = 1 cubic yard. The average face dimensions of the stone were 1.8 feet rise × 3.6 feet long = 6.48 square feet face per stone ; this gave about 19 superficial feet of joint cutting per stone.

The average days' work of a man, deduced from 3½ years' work, in which 5,200 cubic yards were cut, was 6.373 square feet face per day. That is, 1 cubic yard took 1.569 days' work of cutter. Average day's work of superficial feet of joint was 18.7 feet per day.

In cutting the granite for the gate-houses of the Croton Reservoir at 86th street, in New York, in 1861–2, the minimum day's work for a cutter was fixed at 15 superficial feet of joint. This included also the cutting of a chisel draft around the face of the stone, which costs per linear foot about one-fourth as much as a square foot of joint, making the actual limit equivalent to about 17.7 square feet of joint.

On the same work, the proportion to be added to the cost of cutters to give the total cost of stone yard was as follows, for 19 months work :

| | | |
|---|---|---|
| For superintendence | add | 8 per cent. |
| " sheds and tools | " | 7 " " |
| " sharpening tools | " | 11 " " |
| " labor moving stone in yard | " | 10 " " |
| " drillers plugging off rough faces | " | 4 " " |
| Total to be added | | 40 " " |

§ 84. For dimension stone, cut to ¼-inch joints, and hammer-dressed (pean hammered) on the faces, 1 cubic yard takes 9 days' work of cutters. The coping of the dam, composed of two separate courses of stone,

1 of 12-inch rise, 30-inch bed, average length 3½ feet.
1 " 24- " " 48- " " " " 2½ "

top pean hammered, face rough with chisel draft around it, beds and joints to lay ¼ inch, took per cubic yard 6.1 days' work of cutters.

Grooved work for stop plank on upper face of dam as shown in Fig. 4, with fine cut grooves, courses averaging 20 inches rise, took 10.86 days' work of cutters for every foot rise. Steps cut in rock to receive the face wall of dam on northeast end, took 1.2 days' work of cutters per linear foot of face. The above rates are all for granite, or stone of similar hardness.

The stone used for the dam averaged 172 pounds per cubic foot, and the specific gravity as laid in wall with mortar was 2.71.

VII. Laying Masonry.—§ 85. Most of the cut stone was laid by one mason. More than two were not employed at any time. The mason's gang also shifted derricks. The cost of hauling stone to work varied with position of the blocks in the yard and whether they were assorted there into courses, or lay promiscuously.

The cost in time of laying the masonry in each year was as follows :

| Cut Stone Masonry. | 1868. | 1869. | 1870. |
|---|---|---|---|
| Total cubic yards laid | 1070 | 2270 | 2530 |

| | Hand hoist. | Hand hoist. | Steam hoist | Steam hoist |
|---|---|---|---|---|
| Days per cubic yard. | Average 5 feet. | 10 feet to 20 feet. | 20 feet to 30 feet. | 30 feet to 50 feet. |
| Mason | 0.120 | 0 119 | 0.082 | 0.108 |
| Laborers | 0.184 | 0.188 | 0.145 | 0.155 |
| Mortar mixer | 0.100 | 0.082 | 0.076 | 0.101 |
| Derrick and carmen. | 0.327 | 0.341 | 0.235 | 0.261 |
| Engine, hours | | | 0 462 | 0.490 |
| Cement, barrels | 0.314 | 0.304 | | 0.280 |
| Sand, cubic yards | 0.093 | 0.093 | | 0.093 |
| Stone, cubic yards | 0.887 | 0.889 | | 0.900 |
| Teams from yard | 0.100 | 0.056 | | 0.110 |
| Labor loading teams. | 0.184 | 0.223 | | 0.086 |

§ 86. The stones were suspended by two hooks at the ends of a chain, on which was a sliding ring. The hooks were put in notches on the front and back of the stone, made with a stone-cutter's "point." The sliding ring enabled the bed to be slung at any angle. The lower face wall was set with the beds sloping back 2 feet in 5. This inclination caused a good deal of trouble. A stone would rest without sliding when it was first laid on the mortar, but when struck with the maul would slide unless the blow was delivered perfectly square with the stone. This was almost impossible to do, and as a good purchase for a pinch bar could not well be obtained, the masons used blocking against the concrete to hold the stone in place. This had a tendency to throw the rear of the stone up and keep it from its bed. Although apparently a small matter and easily attended to, this is in fact a serious objection to the laying of stone on that slope, when, as in this work there are over 3 miles of stone to be so laid. It is better to diminish the face batter to one-third instead of four-tenths, even if it involved the making of an occasional offset in the wall to reduce the amount of material.

VIII. Brick Masonry.—§ 87. The amount of brick masonry was small, only the arches of the waterways, and the interior walls of the gate-house being laid in brick. The bricks used were "Croton" hard-burned selected brick. The arches were semicular, 4½ feet in diameter, laid in

three rings. The inner ring contained 33 brick, the middle one 38 and the third 42. As laid in the arch, 22 stretchers or 47 headers were 14.90 feet long. 1 cubic yard took 554 brick and 0.95 barrels of cement.

The sizes of brick vary so much in different localities that any estimate based on the number of brick laid has only a limited local value. The proportional number of brick used in different classes of work may be useful. Thus, 1,000 of the same kind of brick, viz.. "Croton hard brick," laid,

| | |
|---|---|
| In lining wall of gate-house substructure, 86th street, New York | 45.2 cubic feet. |
| In flat arch, High Bridge enlargement, New York | 46.0 " |
| In small arches, Storage Reservoir | 48.9 " |

On an average—the weight of these bricks is 4½ pounds each, and they will absorb 19 per cent. of their bulk of water.

The time of masons laying brickwork under inspection varies very much from that in ordinary building. No class of mechanics needs more instruction at the outset, and constant supervision than bricklayers on public works.

In estimating on cost of brickwork, the class of work must be particularly considered. The great difference in cost of different kinds of work is exemplified by the following table of actual cost:

| | Days mason per cubic yard. |
|---|---|
| High Bridge enlargement 1863. Lining wall and flat arch laid with very close joints | 0.714 |
| Washington Aqueduct, 1864. Circular conduit 9 feet diameter, 12 inches thick | 0.439 |
| St. Louis Water Works. Conduit, semicircular arch 6 feet diameter, vertical sides and invert | 0.364 |
| Storage Reservoir, 1869. Lining of gate-house, walls and arch; rather rough work | 0.304 |

ROADS.—§ 88. Three miles of new roads around the reservoir were built by the Department. The section of the road as built is shown in Fig. 3. The road-bed is 16 feet wide with crown of 6 inches, and a ditch 1½ feet deep on the side. All material was removed to a depth of one foot below the grade, and a top dressing of the best gravelly earth in the vicinity, free from stones over 1½ inches in diameter put on and well carted over. Fillings were made with loose rock, and frequent culverts provided. On the reservoir side, retaining walls of boulders, topped with a fence wall 3½ feet high, 2 feet wide at bottom and 18 inches at top, were built. These roads have been in use five years, have

never been repaired and are perfectly good now. The cost of the road, fence-walls and three bridges was $18,172 per mile.

The cost of the dam alone to the completion of the original design (except calking and pointing the upper face) in 1870, was $370,000. The total cost of the reservoir, including land, dam, roads and engineering to the same date was $590,000.

§ 89. In preparing this memoir, an endeavor has been made to present only the results of actual experience, and to aid in supplying a want which is often felt by engineers in estimating the cost of work with the details of which they are not familiar. Every engineer of experience has his collection of memoranda concerning work on which he has been engaged, but when called upon to estimate on another class of construction, data are very difficult to obtain. The estimates of contractors are too frequently based on mere guess-work, as is shown by the very great discrepancy in the bids on every work which is offered at public competition. The only data which can be relied upon are founded on observation of the time actually taken to perform certain operations. With these as a basis, the cost at current prices can be computed. To this cost must be added the amount needed for plant, superintendence and profits, concerning which no rule can be given, as every public work has its peculiarities which require special study, but at the bottom of all is the actual cost of doing the work, and a knowledge of this is essential to making an intelligent estimate.

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